Remarks

Claims 1-8 are pending in this application. Claims 1-8 stand rejected. For the below stated reasons, the Examiner is respectfully requested to withdraw the rejection of claims 1-8 and to allow claims 1-8.

Claims 1-8 stand rejected under 35 U.S.C. §102 (e) as anticipated by United States Patent No. 6,282,218, issued to Anderson on august 21, 2001, entitled CONTROL CIRCUIT WITH AUTOMATIC DC OFFSET, based upon an application Ser. No.. 09/241,319, filed on February 1, 1999 ("Anderson"). The Examiner has taken the position with respect to claims 1-2 and 4-5 that:

> Anderson shows in Fig. 1B lithographic exposures, utilizing a line narrowed gas discharge laser 12 (Col. 3, l. 6-8), comprising of a control computer 56 (col.9, l. 51-53) to determine a desired laser spectrum and a fast responding tuning mechanism 76 (col. 8, l 44-65).
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> Anderson discloses:
>
> An automatic gain control circuit in the feedback path for a laser wavelength control circuit is described herein. This gain control circuit automatically adjusts the amplification of the analog signals output from a photodetector array, where the array detects a fringe pattern created by a laser beam. Another feature of the preferred embodiment feedback circuit is the automatic setting of a DC offset voltage that compensates for errors in the feedback path and enables an accurate determination of a dark level signal in the fringe pattern signal. (Abstract)
>
> Anderson also notes:
>
> Microprocessor 56 continually monitors the digital output of the A/D converter 58. A/D converter 58 outputs a digital value for each photodiode 32 signal in the PDA 30. (Col. 6, lines 15-18)
>
> Further notes Anderson:
>
> The A/D converter 58 output is applied to an input of microprocessor 56 for calculating the diameter of selected fringe rings (or other dimensions of the fringe rings), using an algorithm, to thus identify the wavelength of the laser beam. (Col. 8, lines 25-29)
>
> Still further Anderson discloses:

> Microprocessor 56 then applies control signals to laser wavelength adjustment circuitry 76 for suitably adjusting the wavelength or other characteristic (e.g., spectral width) of laser 12 (step 11). Such laser wavelength adjustment circuitry 76 may be any type of adjustment circuitry used in the industry or described in any publication. In response to the wavelength detection signal or other control signal from microprocessor 56, laser 12 is adjusted by either mechanically adjusting the laser structure, such as by means of a stepper motor, or by adjusting certain optical components, or by adjusting a gas mixture in laser 12. Examples of various tuning methods and devices are described in the patents previously mentioned, incorporated herein by reference. Typically, the laser wavelength will be slewed up or down until microprocessor 56 detects the wavelength or other characteristic meets a desired criteria. Accordingly, microprocessor 56 may simply output an up or down control signal to adjustment circuitry 76.
>
> Microprocessor 56 may also be programmed to determine the energy level of each pulse as well as the spectral width (based on the width of the fringe signals) of each pulse for use in characterizing the performance of the laser. (Col. 8, lines 44-65)

With respect to claim 1, this disclosure of Anderson has nothing to do with the invention claimed in claim 1, i.e., "modeling with a computer program lithographic parameters to determine a desired laser spectrum needed to produce a desired lithographic result" or also "adjust[ing] the center wavelength of laser pulses in a burst of pulses to achieve an integrated spectrum for the burst of pulses approximating the desired laser spectrum." For these reasons, claim 1 is not anticipated by Anderson and neither then are claims 2 and 4-5. *In re Fine*, 837 F.2d 1071, 5 U.S.P.Q.2d 1596 (Fed. Cir. 1988)

Claim 3 is also dependent from the allowable claim 1 and should also be allowed with claim 1. *In re Fine*, 837 F.2d 1071, 5 U.S.P.Q.2d 1596 (Fed. Cir. 1988)

Respecting claims 6-8 the Examiner has taken the position that "it is inherent that the desired laser spectrum could have two or more separate peaks with tht peak spectrum separation of at least 0.5 picometer based on the adjustments of the computer program lithographic parameters by the operators."

One of the aspects of an embodiment of the inventions claimed in the above captioned application is explained in the Specification, as follows:

> The limitations of acceptable optical lens materials to fused silica and calcium fluoride for use with deep ultraviolet light at 248 nm and 193 nm wavelengths have meant that projection lenses for KrF and ArF lithography, to a large degree, cannot be corrected for wavelength variations. Chromatic aberrations emerge since the index of refraction of any optical material changes with wavelength, and hence, the imaging behavior of a lens also varies with wavelength.
>
> The detrimental effects of chromatic aberrations for an uncorrected lens can be mitigated by using a light source with a very narrow range of wavelengths. Spectral line-narrowed excimer lasers have served this purpose for deep-UV lithography. In the past, laser specifications have required the FWHM bandwidth to be smaller than a specified value such as 0.5 pm but with no lower limit on bandwidth. Specifications are also directed at the 95 percent integral bandwidth. A typical 95% I specification would be less than 1.2 ppm. However, recently integrated circuit manufacturers have noticed that the quality of their integrated circuits can be adversely affected by bandwidths, such as about 0.35 pm FWHM, which are substantially narrower than the bandwidths for which their optical systems were designed.
>
> A lithography technique, called FLEX (short for, "focus latitude enhancement exposure") has been shown (through simulation and experiment) to improve the depth of focus by utilizing multiple exposure passes of the same field with different focus settings. This technique is also commonly referred to as focus drilling, since the physical thickness of the photoresist film is exposed in multiple passes at incremental focus settings. The image in photoresist is formed by the composite of the multiple exposure passes.
>
> Several difficulties result from this FLEX process with both step and scan as well as step and repeat exposure implementations. Multiple pass exposure results in additional overlay (image placement) errors and image blurring. This

has further implications on process latitude, focus repeatability as well as wafer throughput since multiple exposures require multiple imaging passes.

What is needed is a better technique for providing improved quality integrated circuit lithographic exposures. (p. 3, line 1 – p4, line 5)

Applying the present invention to the solution of the above referenced problem(s) the present invention calls for:

The present invention provides an integrated circuit lithography technique called spectral engineering by Applicants, for bandwidth control of an electric discharge laser. In a preferred process, a computer model is used to model lithographic parameters to determine a desired laser spectrum needed to produce a desired lithographic result. A *fast responding tuning mechanism is then used to adjust center wavelength of laser pulses in a burst of pulses to achieve an integrated spectrum for the burst of pulses approximating the desired laser spectrum*. The laser beam bandwidth is controlled to *produce an effective beam spectrum having at least two spectral peaks* in order to produce improved pattern resolution in photo resist film. Line narrowing equipment is provided having at least one piezoelectric drive and a fast bandwidth detection control system having a time response of less than about 2.0 millisecond. (p. 4, lines 9-20)

Further:

In another embodiment, the *maximum displacement was matched on a one-to-one basis with the laser pulses in order to produce a desired average spectrum with two peaks for a series of laser pulses*. Other preferred embodiments *utilize three separate wavelength tuning positions producing a spectrum with three separate peaks*. (p. 4, lines 23-28, emphasis added)

As a further explanation of aspects of an embodiment of the present invention, the specification goes on to point out:

Simulation of the effects of wavelength and bandwidth changes have been performed by Applicants. *The main effect of changing the exposure wavelength for a non-chromatic corrected lens is a change in the position of the focal plane*. Over a fairly wide range of wavelengths, this change in focus is approximately linear with the change in the nominal wavelength (i.e., the central wavelength of

the illumination spectrum). The wavelength response of a lens can be determined experimentally by manually changing the central wavelength of the laser and using the imaging sensor of the stepper to monitor the shift in focus that results. *FIG. 1A shows an example of such a measurement.*

Given the change in focus with change in wavelength, the use of a broadband illumination spectrum means that each wavelength in the spectrum will produce an aerial image with a different best focus. The total aerial image will be a sum of the aerial images at each focal position, weighted by the relative intensity of each wavelength in the illumination spectrum. This technique is based on multiple focal plane exposures. Latest versions of a computer program PROLITH/2 (available from KLA Tencor with offices in Austin, Tex.,) incorporate these types of effects. Actual laser spectra measured on a variety of commercially available lasers were used in this work to represent laser spectra. FIG. 1B illustrates three examples of KrF laser spectra.

In order to understand the impact of laser bandwidth on the lithographic process in the presence of chromatic aberrations, Applicants started from investigation of the aerial image of a 180 nm isolated line. FIG. 3 shows how changing bandwidth affects the aerial image under a specific set of conditions. (The image dimension is usually assumed to correspond to the 0.3 image intensity values.) For these simulations the following input parameters were used: NA=0.6, σ=0.75, λ_0=248.3271 nm. Laser spectra with 0.5 pm, 1.2 pm, 2.1 pm bandwidths at FWHM and a monochromatic light source were used in this simulation study, and a chromatic aberration focus response of 0.225 μm/pm was assumed. As can be seen in FIG. 3, changes in the bandwidth causes noticeable changes in the image intensity distribution.

The impact of laser bandwidths on critical dimensions (CD) variations of isolated lines with different sizes was evaluated using an aerial image threshold model. In this study the following lithography input parameter settings were used: σ=0.75, λ_0=248.3271 nm, aerial image threshold at 30%, NA=0.6, 0.7, and 0.8. The simulations were performed for isolated lines ranging from 240 nm to 140 nm. The chromatic aberration response was assumed at 0.225 μm/pm. As shown

in FIGS. 4A, 4B and 4C, changes in the bandwidth (either increases or decreases) can result in substantial changes in the critical dimensions of the integrated circuit lines especially at higher numerical aperture values. As shown in FIGS. 4A-4C the smallest bandwidth (i.e., 0.35 pm) produces the smallest change in the critical dimension as a function of mask dimension. A reader might conclude from this data that lithography systems should be designed for the smallest possible bandwidth. The problem with that approach is that maintaining the bandwidth consistently at 0.35 pm over the life of the light source would be very difficult and expensive with today's technology. Therefore, the normal practice is to design lithography systems for best performance at a bandwidth which is somewhat larger than the smallest possible bandwidth, such as about 0.5 pm. But if a lithography system is designed for best performance at 0.5 pm, an "improvement" in the laser bandwidth down to 0.35 pm will often lead to a worsening of critical dimensions and decreased quality of the integrated circuit. (p. 6, line10 – page 8, line 2, emphasis added)

The Specification in the above captioned application goes on to even further explain:

Applicants have shown that substantial improvements in lithographic imaging can be provided using a spectral engineering techniques developed by Applicants. Applicants refer to this technique as RELAX which is an acronym for Resolution Enhancement by Laser-Spectrum Adjusted Exposure. In these techniques, the wafer is illuminated with two or more specific narrowband centerline wavelength during a single illumination period. This produces results which are improved over the dither technique referred to above. The results are similar to the FLEX technique discussed in the background section of this specification but constitutes a major improvement over FLEX since Applicants' technique involves only one positioning of the lithography equipment. Therefore, errors associated with adjustments of this equipment are avoided.

Dual Mode Illumination

The results of simulations performed by Applicants show proof of concept for use of a dual-mode illumination spectrum to improve resolution in photo resist

film. In this dual mode simulation work, Applicants simulated the process parameters for 200 nm isolated, semi-dense (1:2) and dense (1:1) contact hole patterns. A binary (chrome on glass) reticle pattern and conventional illumination (e.g., a stepper system with a numerical aperture, NA of 0.7 and a 0.75 sigma) at KrF exposure central wavelengths, (λ_0=248.385 nm) were modeled in the simulation. The photo resist was modeled as UV6, 5200A casting thickness on AR2 bottom anti-reflective coating in order to quantify the obtained resolution enhancement of the imaged pattern. The double-mode spectrum used as the simulation input is shown in FIG. 2B. In this case, the spectrum is generated by summation of a single mode (nominal) spectrum (bandwidth: FWHM=0.45 pm, E95%=1.86 pm) and its copy with a 4 pm wavelength offset. If S(λ) represents the spectral density function of the nominal (0.45 pm/1.86 pm FWHM/E95%) spectrum, the spectral density of the double-peak RELAX spectrum [SRELAX(λ)] can be expressed as SRELAX(λ)=S(A)+S(λ+4 pm). Technologies for actual generation of such spectral properties are discussed in the following section. The longitudinal focus plane to centerline wavelength slope used for this model is -0.225 .mu.m/pm which is shown in FIG. 2A.

The results of this simulation of the double-peak RELAX technique are compared in FIG. 2C with similar simulations of a monochromatic beam and a conventional single peak spectrum with FWHM bandwidth of 0.45 pm and a 95% integral bandwidth of 1.86 pm. The critical dimension response to focus and dose are presented for 1:1 dense contact holes for three illumination spectral distributions; (1) monochromatic illumination, (2) conventional laser spectrum and (3) the 4 pm double mode RELAX illumination with a spectrum as shown in FIG. 2B (i.e., two 0.45 pm FWHM spectral bands with centerlines separated by 4.0 pm).

FIG. 2D presents plots of the resist feature widths of holes which have a target diameter of 200 nm as a function of depth of the holes. The figures are plotted for several doses ranging from 17 J/cm^2 to 26 J/cm^2 in the monochromatic example and from 25 J/cm^2 to 32 J/cm^2 in the RELAX example. This ordinant is feature width and the absissa is labeled focus but actually represents the depth of

the feature in microns with zero taken as the focal plane of the centerline wavelength. An "ideal" graph would be a straight line at 200 nm over a depth of at least 1.0 micron, with insignificant variation in width with exposure dose. The FIG. 2C [as amended] plots reveal that the RELAX simulation produces a set of plots much closer to the "ideal" graph than either the conventional or monochromatic example.

FIG. 2D is another set of graphs made from the same data as was used for the FIG. 2C plots. In this case, Applicants selected the plot for each of the examples and plotted for that exposure the exposure latitude (i.e., the percent of the dose can vary without causing the critical dimension to vary more than 10% from a target value) as a function of the depth of a hole having a target width of 200 nm. Again, these three graphs show a great improvement in performance resulting from the use of the RELAX techniques.

The dramatic improvement in the depth for which the critical dimension can be controlled to within 10% with the RELAX approach is apparent. The improvement in depth of focus is larger than fourfold at the 5% exposure latitude level compared to the monochromatic and conventional results for dense contacts. Some exposure latitude loss is observed by using the double-mode spectrum. This loss in exposure latitude is most pronounced near best focus (i.e., 0.0 depth of focus). As compared with the conventional spectrum example, the slight increase in the target dose (from about 25 mJ/cm.sup.2 to about 29 mJ/cm.sup.2) for the RELAX case as compared to the conventional example should be noted.

The simulation results for the other pattern configurations referred to above were tested with the result that the two-peak RELAX technique produced better pattern resolution as compared to both monochromatic and the conventional spectrum for every example tested. Therefore, we conclude that the RELAX application (using a dual-mode spectrum with 4 pm mode separation) for focus drilling provides dramatic improvement in the overall process window area. A tradeoff is realized between depth of focus improvement and loss of exposure latitude, however, the DOF increases at a higher rate than the reduction of exposure latitude. In contact hole imaging especially, as well as many other

imaging applications of lines and spaces, the DOF is a limiting process performance factor. Isolated lines and line-space patterns are also expected to exhibit process window changes for modified illumination spectra. Examples Using Two Centerline Wavelengths

Applicants have demonstrated the feasibility of technique for wavelength control needed for this spectral engineering as shown in FIGS. 2E and 2F. PZT driver 80 shown in FIG. 5A was programmed to control the wavelength of a KrF laser operating at 120 Hz to adjust each pulse by plus or minus steps of 4.0 pm. The integrated intensity values recorded on wavemeter photodiode array 180 shown in FIG. 6 are plotted in FIG. 2E. This plot shows sharp peaks at pixel 450 and 618 which correspond to a centerline wavelength shaft of 4.0 pm.

Similar results are shown in FIG. 2F where the PZT driver is driven in a sine wave to vary the wavelength by about 2 pm at a frequency of one half the laser pulse rate of 120 Hz.

Optimization of Laser Spectrum

The basic concept behind spectral engineering is to determine, using lithography simulation, the optimal spectral shape, which will provide the maximum improvement of a given parameter. In particular examples, lithography simulations are provided for two dual-mode illumination spectra and three three-mode illumination spectra shown in FIGS. 2G1, 2G2 and 2G3. In these examples, the parameter, which is maximized is the depth of focus, for 150 nm dense lines. From FIG. 2H1, we see that the two dual-peak spectra (3 pm and 4 pm separation) are least sensitive to defocus and therefore have a maximum depth of focus. From the depth of focus changes, it appears that spectral modification (going from monochromatic, to three to two mode illumination spectrum) provides significant (up to 2.times.) improvement of DOF. From this alone, either the 3 pm or 4 pm dual-mode illumination appears optimal for imaging of these features.

If we consider the tradeoff between exposure latitude (EL) and depth of focus as a function of the different illumination spectra (shown in FIG. 2H2), we may choose to use the 1.5 pm-offset 50% weighted three-mode illumination in order to prevent the reduction in exposure latitude below 12% at best focus. The

three-mode spectrum still provides an appreciable increase in depth of focus. In addition the three-mode spectrum (with 1.5 pm peak separation) provides the least amount of contrast loss from the monochromatic case as shown in FIG. 2H3.

From this 150 nm dense line example, it is clear that the implementation of RELAX requires a very careful tradeoff design in order to maximize the benefits of a subset of imaging parameters at lowest cost to other parameters. The RELAX application will therefore be most successful in cases where a single parameter limits the overall process margin (process latitude). In that case, the limiting process parameter can be improved (relaxed) in order to improve to overall process margin for manufacturability. Optical proximity correction (OPC-resolution enhancement technique using reticle feature corrections) can be used in conjunction with RELAX for comprehensive lithography process engineering and maximum benefits.

The tuning of the RELAX spectral illumination, from a continuum of theoretical choices can be done using lithography simulation and an iterative optimization algorithm. (p. 10, line 9 – p. 14, line 18)

Nothing in the art makes inherent the recognition of the above noted lithography problems and their solution through "utilizing a fast responding tuning mechanism to adjust center wavelength of laser pulses in a burst of pulses to achieve an integrated spectrum for the burst of pulses approximating the desired laser spectrum," and further that that integrated spectrum "comprises two or more separate peaks" or that they are "separated by at least 0.5 picometer" or that they are "three separate peaks." For these reasons, the rejection of claims 6-8 as being inherent is clearly improper. In any event claims 6-8 depend directly or indirectly from the allowable claim 1. *In re Fine*, 837 F.2d 1071, 5 U.S.P.Q.2d 1596 (Fed. Cir. 1988)

Furthermore, Anderson is not proper prior art against the above captioned application assigned to the same assignee as Anderson. 36 U.S.C. §103 (c)

For the above stated reasons the Examiner's rejections of claims 1-8 are not proper and the Examiner is respectfully requested to withdraw the rejections of claims 1-8 and allow claims 1-8.

New claims 13-36 reciting further aspects of the present invention should also be allowable.

Conclusions

Applicants believe that claims 1-8 presently pending in this application are allowable and respectfully request that the Examiner withdraw the rejection of claims 1-8 and allow claims 1-8. Applicants submit that new claims 13-36 should also be allowable and respectfully requests that they be allowed.

Applicants have submitted a Supplemental Information Disclosure Statement.

Applicants hereby authorize the Commissioner to charge the Deposit Account of applicants' assignee, Cymer, Inc., Deposit Account No. 03-4060 the amount of $198 for the additional claims and $180 for the filing of the Supplemental Information Disclosure Statement. Applicants do not believe that any additional fees are due for this Response, but in the event that any additional fees are due, applicants authorize the Commissioner to charge any such fees, or to credit any overpayment to the just referenced Deposit Account.

Respectfully submitted,

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